2018 DOE Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting

Cummins Electric Truck with Range-Extending Engine (ETREE)

Project ID: ELT189

Principal Investigator:
John Kresse
Cummins, Inc.

June 20, 2018

Project Overview

TIMELINE

- 40-month project
- Project start date: July 2016
- Project end date: Nov 2019

BARRIERS

- EV-based commercial vehicle which meets needs of class 6-7 pickup & delivery fleets:
  - Complete the route regardless of environmental conditions with little to no performance degradation
  - Robust, cost-effective powertrain which emphasizes use of grid electricity

BUDGET

Project (overall):	$6,295,281
DOE Share:	$4,126,570
FFRDC:	$355,708
Contractor funding:	$1,813,003
Funding received (1/2018):	$3,207,815

PARTNERS

- Cummins
  - PACCAR
  - Argonne National Lab
  - National Renewable Energy Lab
  - The Ohio State University

Objectives

(1)

- Using electrification, improve the Kenworth K270 & Peterbilt Model 220 to substantially reduce fuel consumption for the **class 6 pickup & delivery market** while meeting requirements of the existing trucks
- Investigate the potential to improve a commercial EV using:
  - range extending engine / generator
  - multi-speed transmission
  - electronic braking system with brake blending
- Develop hybrid system controls technology focused on battery state-of-charge trajectory management and vehicle integration (electrified accessories, thermal management) systems
- Define and verify requirements for range extending electric trucks applicable to class 6-7 pickup and delivery application

1. Courtesy of PACCAR Inc

Relevance of ETREE project

- Two keys to widespread electrified commercial vehicle adoption
  1. For pure EV, battery improvements are needed: cost(↓) & energy capacity(↑)
  2. Must overcome fleet operator risk (purchase, operational)
- In the near- to medium-term, solved by: a PHEV w/ low-cost range extender to provide route flexibility
    - Proven to work over wide variety of missions & environmental conditions
    - Manufactured, serviced, certified, delivered, integrated using standard commercial vehicle processes
- Vehicle developed in this project can be considered a prototype for a commercially viable heavily electrified commercial vehicle
- ETREE will deliver equivalent continuous performance (transmission output torque and power) and range as conventional class 6 truck

EV – electric vehicle PHEV – plug-in electric vehicle

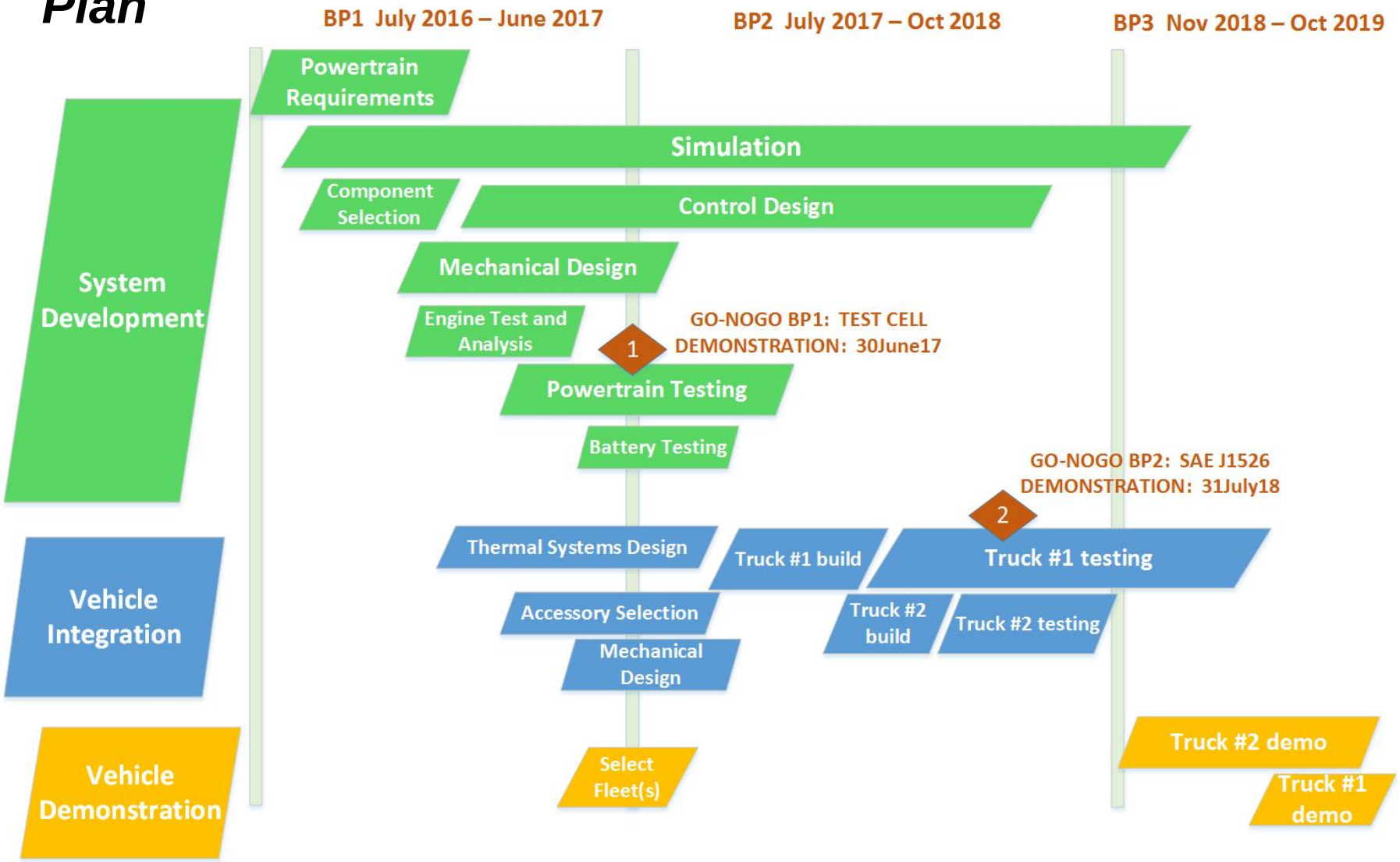
Milestones

Milestone	Budget Period	Scheduled Completion	Actual
Fuel consumption reduction objectives met in test cell	1	6/30/2017	6/6/2017
Fleet demo partner selected	1	6/30/2017	8/27/2017
Battery tested in lab	2	7/31/2017	8/7/2017
Powertrain testing in test cell complete	2	10/15/2017	9/22/2017
Truck 1 operational	2	2/27/2018	
SAE J1526 testing complete & fuel consumption reduction achieved at TRC	2	7/30/2018	
Release truck to first fleet operator	3	11/1/2018	

Any proposed future work is subject to change based on funding levels

Approach

Plan



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Approach

Selection of Fleet Demo Partner

- **Frito-Lay** selected as primary ETREE demo partner
  - Operates fixed defined routes, 15-100+ mi/day, delivering chips/snack food
  - ETREE Peterbilt Model 220 will operate on 50-80 mi/day routes from the Indianapolis distribution center
- PepsiCo / Frito-Lay is a significant proponent and adopter of alternative fueled, including electrified, vehicles, and one of the largest operators of class 6-7 trucks

"'The Range Extended capability of the ETREE vehicle is of great interest to PepsiCo. It provides real world opportunity for zero emission driving and also the ability to drive extended miles when needed, with no interruption"

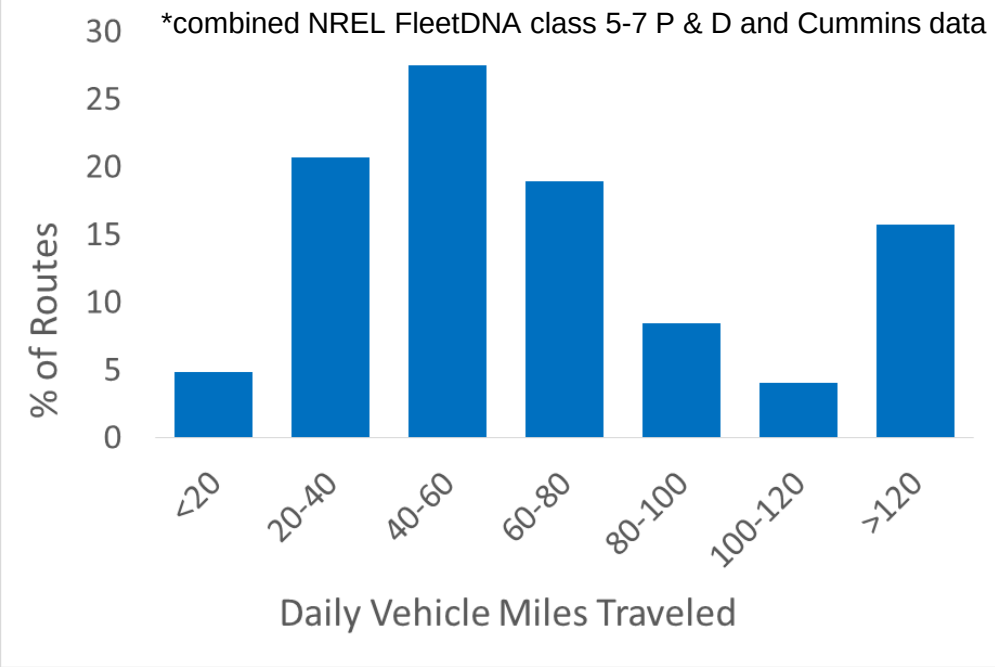
- Mike O'Connell (VP Fleet, Supply Chain and Sustainability) PepsiCo

Logos courtesy of PepsiCo, Inc.

Approach

Understanding Customer Requirements

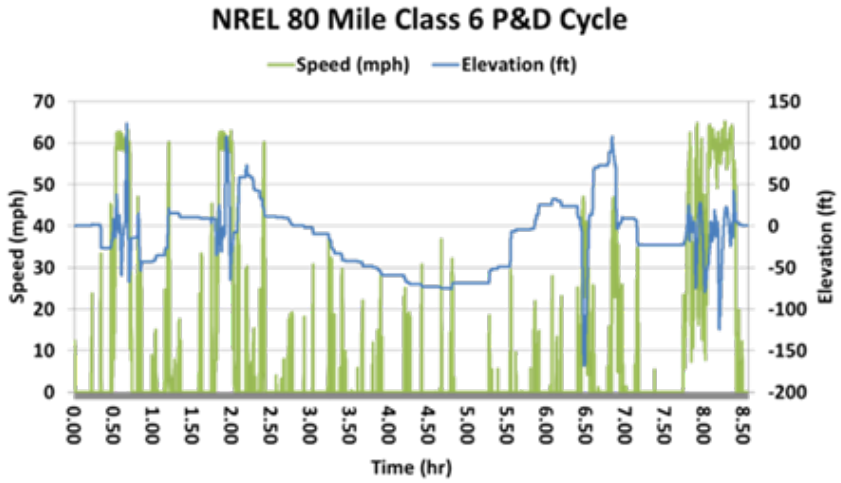
- For class 5-7 pickup & delivery, fleet operators want truck with:
  - comparable performance as conventional and, generally, desire range flexibility provided by a range extender
  - capability to operate in pure electric mode
- Also: require low installation cost of charging infrastructure (EVSE), trucks often stored outside & may not have dedicated EVSE per truck



Approach

Translation into Design Requirements

Fuel consumption reduction	≥ 50% on typical class 6 P & D routes
Performance, Startability	Equivalent to conventional
Gradeability	Equivalent to conventional for ≥ 10 minutes
Vehicle range (fuel + battery)	≥ 270 miles
Payload	≥ 7000 lb
Truck body	24’ box with lift gate

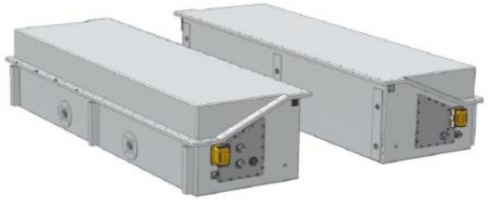


- **NREL 80 mile developed as the ETREE target cycle**; represents 70-80th percentile of required energy of representative drive cycles*
- Secondary target duty cycle developed: NREL 100 mile cycle

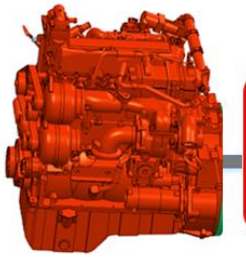
*Duran, A., Le, K., Kresse, J. and Kelly, K. “Development of 80- and 100- Mile Work Day Cycles Representative of Commercial Pickup and Delivery Operation,” SAE Technical Paper 2018-01-1192

Approach
Architecture

Architecture & ancillary components selected to meet customer requirements on target duty cycle(s)



112 kW-h NMC
Li-ion battery



damper

130 kW
PM generator

~/-

-/~

165 kW
PM traction
motor

Allison 3000 ETREE
transmission

Transmission input
stop-start system

155 kW ISB4.5 with
DPF, SCR, DOC aftertreatment

700 V DC bus
nominal

DPF – diesel particulate filter
SCR – selective catalytic reduction
DOC – diesel oxidation catalyst
NMC – nickel manganese cobalt

Permanent magnet (PM) electric machines with listed continuous ratings

- **J1772 level 2 EVSE** [supports low cost infrastructure]
- **WABCO Electronic Braking System** w/ torque blending between service brakes and traction motor control [enables similar driving experience as conventional]
- **Electrified accessories** [supports electric-only operation]

Technical Progress

Demonstrated fuel consumption reduction in test cell

Duty Cycle	baseline	ETREE	Simulated Fuel Reduction [%]	baseline	ETREE	Tested Fuel Reduction [%]
	Simulated fuel used (lb)			Tested: test cell fuel used (lb)		
NREL 80	69.7	23.3	**66.5%**	68.8	24.4	**64.6%**
NREL 100	94.2	40.6	**56.9%**	90.9	48.2	**53.0%**

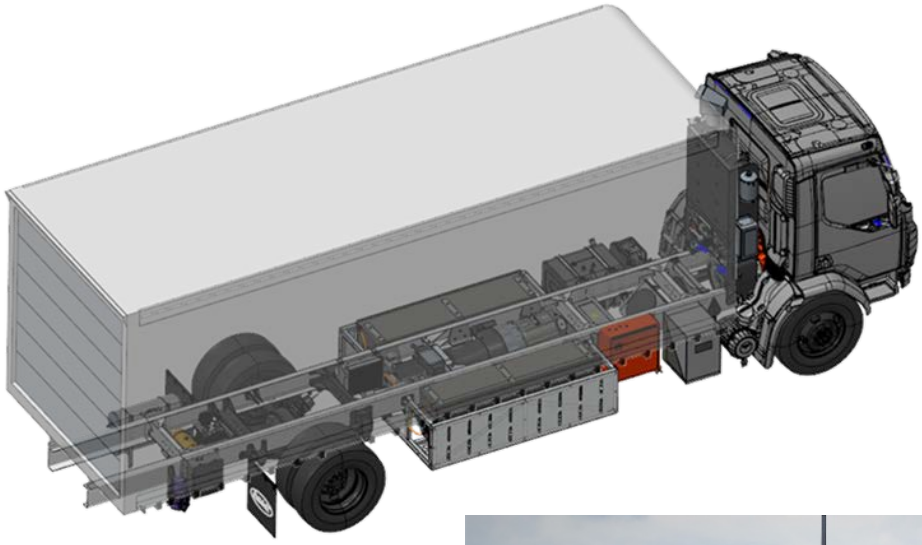
Target >50%

Results shown here with high levels of kinetic energy recovery; actual reduction will likely be 3-4% lower in practice

Not shown:
250 kW battery emulator, engine aftertreatment

Technical Progress

Vehicle design, systems integration, build

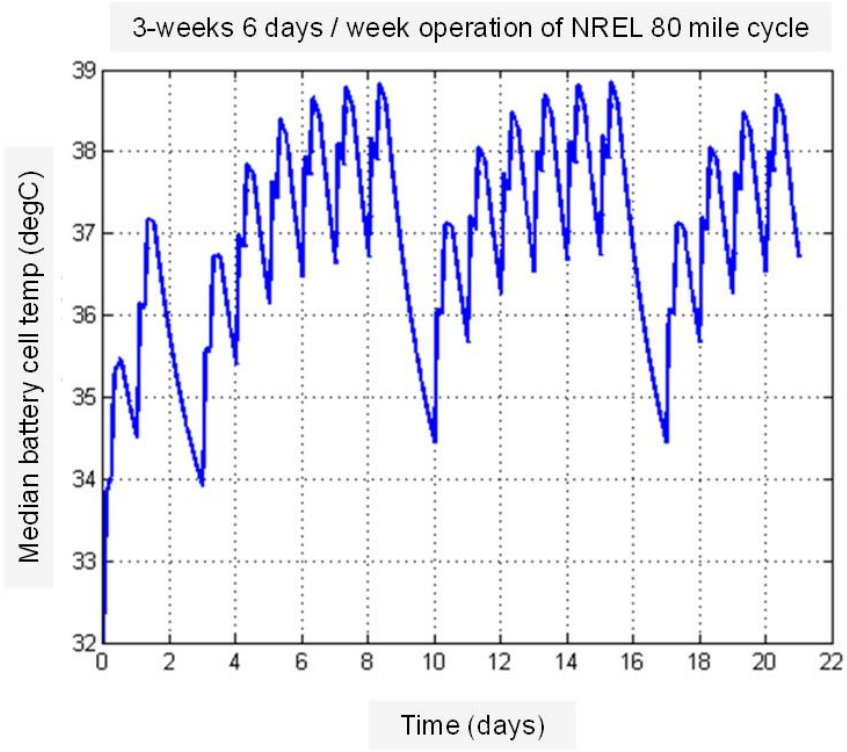


Technical Challenge

Use of passive cooling for high energy Li-ion battery

- Validated battery thermal model used to predict median cell temperature over a 3-week NREL 80 mile cycle with $T_{ambient}$ = 32 degC

- With cell-to-cell variation expect worst case max cell temp < 45 degC
- **Conclusion: operating in Midwest US is acceptable for demonstration**
- Range extender could be used under extreme ambient conditions to limit battery temperature increase
- For production, to support different geographic locations and use cases, active thermal management likely required



Technical Challenge

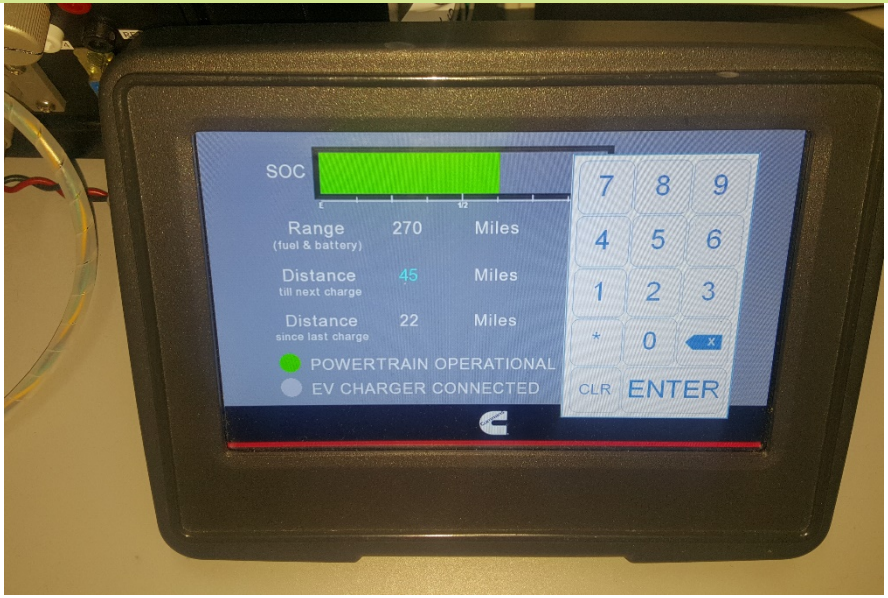
Maximize daily use of battery

- Using route information (driver entered & learned parameters), range extender logic:
  - Reduces fuel consumption
  - Maximizes battery life
  - Manages aftertreatment temperature
  - Meets performance metrics

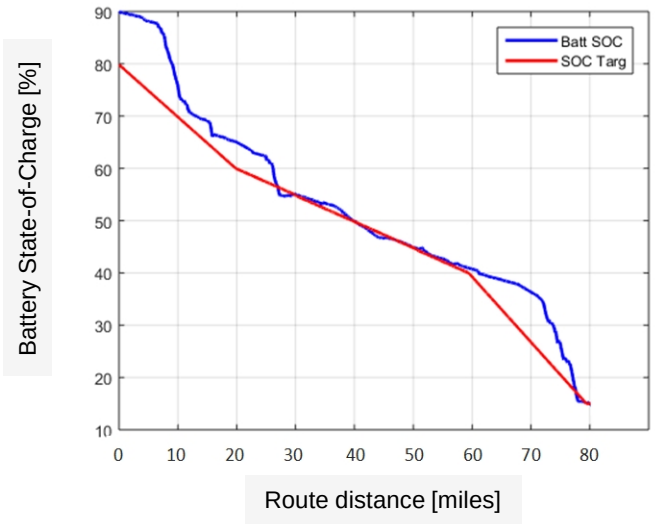
Range extender power capability < (Traction motor + accessory) required power, simply employing charge depleting / charge sustaining not an option. ETREE is using a:

mix of charge depleting, charge sustaining and blended operation

HMI enables driver to enter route distance

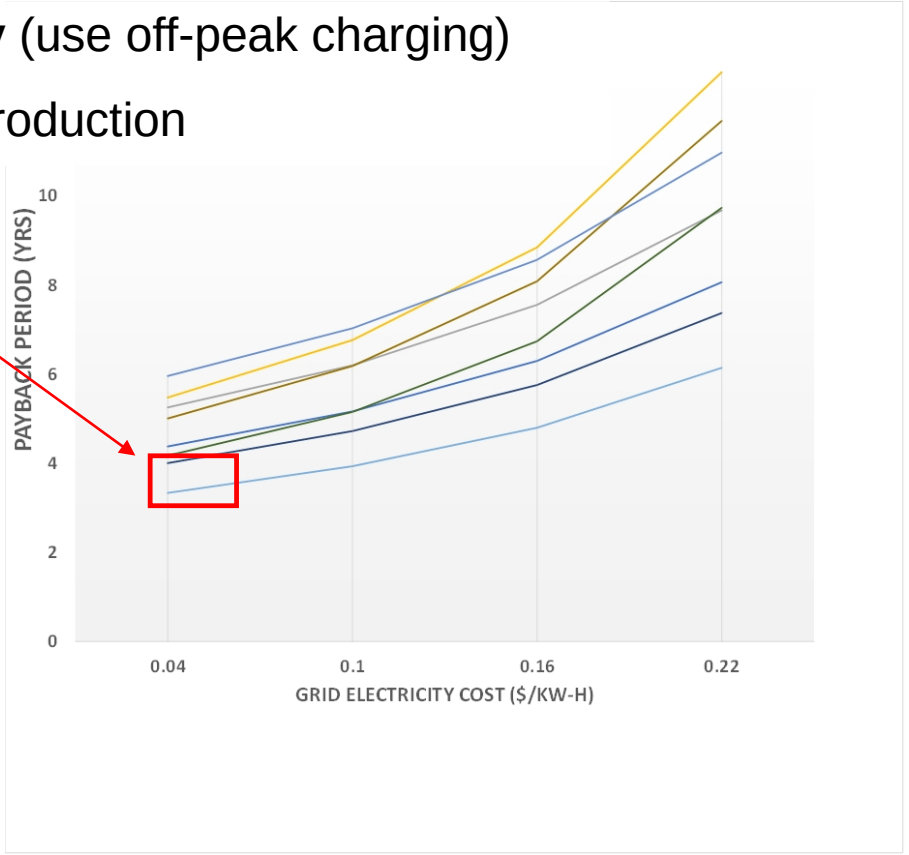


State-of-Charge trajectory during work day



Commercial viability

- To minimize payback period, need to:
  - **maximize battery use** by 1) selecting routes with appropriate distance and energy requirements & 2) operating 6x/week
  - **minimize cost of grid electricity** (use off-peak charging)
- As currently configured, low volume production ETREE payback period ~4 years if:
  - ETREE operating 6x/week
  - daily VMT*: 55 - 110 miles
  - grid electricity cost ≤ 4 ¢/kW-h
- Near 3 year payback period is possible with a smaller range extender (engine + generator) while still meeting desired performance



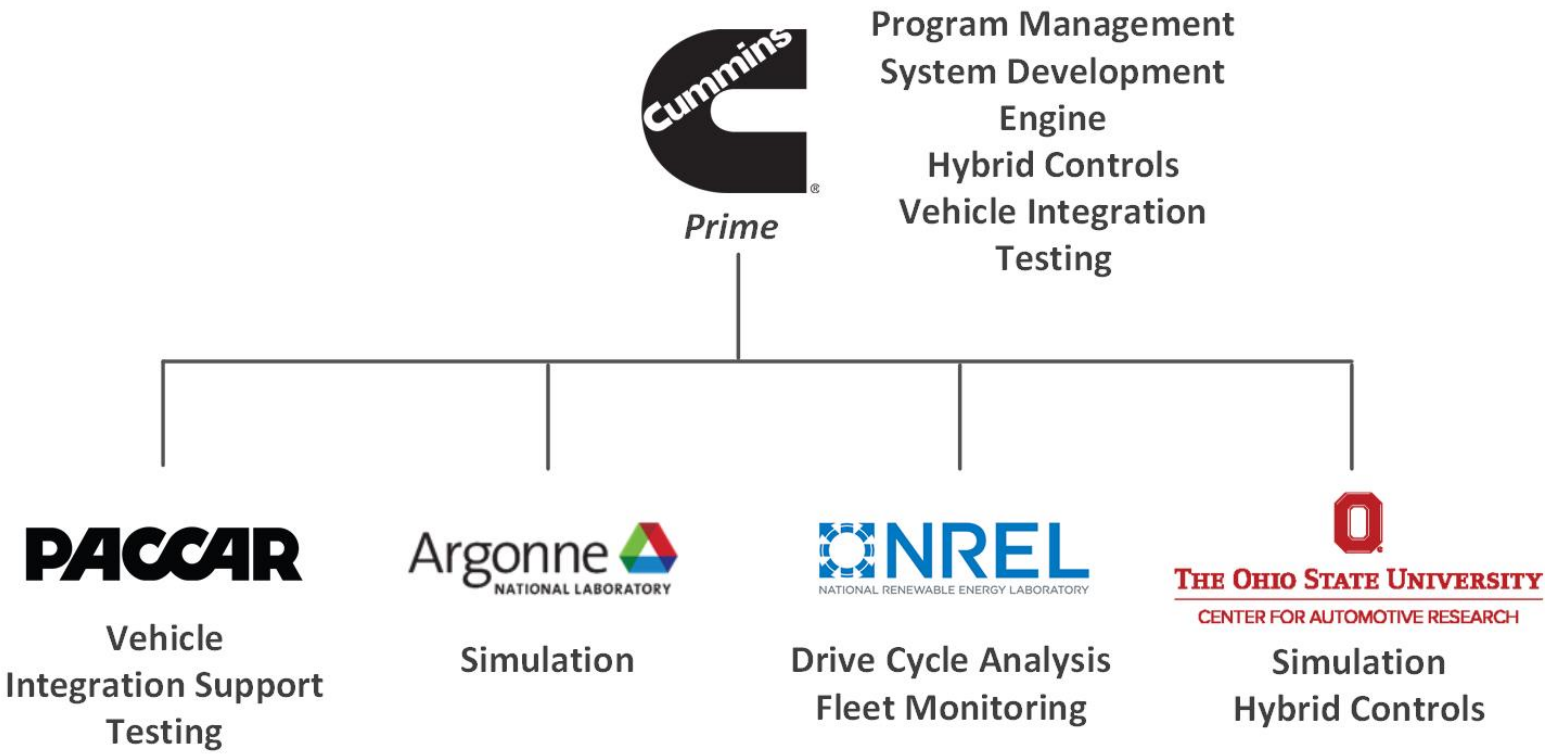
*VMT = vehicle miles traveled

Response to Reviewers' Comments from 2017 AMR

- Several comments were made about lack of discussion about **commercial viability** [addressed in slide 15 of this presentation]
  - "*The goal of having a commercially viable vehicle was not addressed and should be.*"
- A comment was made regarding **lack of selected fleet operator**
  - Frito-Lay / Pepsico and Alpha Baking (Chicago) are now selected as fleet demonstration partners and have been providing valuable feedback
- *"The **TMS (thermal management system) being air cooling** is a concern"* [addressed in slide 13 of this presentation]
- *"[Presentation] did not list **risks of barriers or have risk mitigation** identified".*

Risks	Risk mitigation
Air cooled battery	Slide 13
To meet project goals, must maximize battery usage without impacting vehicle performance	Slide 14
Interaction of systems, impact of component failures on vehicle operation	Extensive vehicle validation, FMEA/FMET
Operation when cold (battery, charging, not having full time access to EVSE)	Simulation, extensive validation, cold box testing

Collaboration



Key Suppliers	Allison Transmission, Inc. – transmission, stop-start system
	WABCO – electronic braking system
	Analytical Engineering, Inc. – vehicle build assistance
	Transportation Research Center – testing
	Morgan Corporation – van body

Remaining Challenges & Future Research

- Vehicle validation
  - Battery operation
  - Interaction of thermal management systems
  - Verification of range extender strategies
  - Electronic Braking System (EBS) validation
- Truck 1
  - Validation at Cummins
  - TRC* test track J1526 Type II (8/2018)
    - Translation of NREL 80 to test track cycle
    - Budget Period 2 Go/no-go milestone
  - PACCAR Technical Center (2/2019)
  - Alpha Baking, Chicago (3/2019 – 9/2019)
- Truck 2
  - Frito-Lay, Indianapolis (11/2018 – 10/2019)

(1)

(2)

(3)

Any proposed future work is subject to change based on funding levels

*Transportation Research Center

1, 3. Courtesy of Transportation Research Center Inc.
2, Courtesy of PACCAR Inc.

Summary

- Team has developed an electrified powertrain capable of meeting the project objectives
  - Delivers at least 50% fuel consumption reduction for a wide range of class 6 pickup and delivery drive cycles
  - Comparable performance to conventional Kenworth K270
  - Verified, in powertrain test cell testing, fuel consumption reduction target can be met on primary and secondary target duty cycles
- PepsiCo/Frito-Lay and Alpha Baking selected as fleet operators
- Vehicle testing is progressing to meet second year go / no-go milestone with risk to timing
- Vehicle validation is focus for balance of Budget Period 2 and into start of Budget Period 3

Any proposed future work is subject to change based on funding levels

Q+A


Cummins